# Towards Energy Analysis and Efficiency for Sustainable Buildings

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## Abstract

Energy analysis that leads to energy efficiency becomes one of the most important factors in the building design process, especially considering the current energy crisis and the effects of global warming. Building designers greatly benefited from the review and analysis to optimize energy usage for the building in the design stage. While the current design approach is mostly done manually, this paper presents the automated version using the developed BIM plugin. It eases the designer's choice of alternative plans that yield an effectively designed building. The development of energy analysis in the application aims to promote energy efficiency by calculating the energy consumption estimation based on energy codes MS2680 and MS1525. This application is improved by a simulation that uses the Building Information Modeling (BIM) platform and extracts the necessary parameters from the BIM model with the aid of the created plugins. This study measured energy consumption and efficiency using the two primary parameters of Overall Thermal Transfer Value (OTTV) and Roof Thermal Transfer Value (RTTV). According to the results, OTTV reaches 42.72% and RTTV reaches 8.02%, both of which respectively meet Malaysian Energy Code limits of less than 50% and 25%.

## 1- Introduction

Every nation is now very concerned about the issue of energy use [1, 2]. Architecture, engineering, construction, and facility management (AEC / FM) are now starting to address the demand for energy-efficient buildings due to the growing threat of global warming, rapid technological innovation, and rapid economic development [4, 5]. As a result, energy analysis has become one of the most important factors in building design and is increasingly important as energy crises and global warming worsen daily [4]. A more energy-efficient design facility can be created by selecting design choices that consider the potential energy consumption of buildings at the design stage [6, 7].

The Malaysian government has launched a few efforts to improve energy efficiency over the past ten years. To create a green nation by 2020, the Department of Public Works Malaysia (PWD) has adopted more and more measures to develop, adapt, and enforce sustainable project management across the building lifecycle, including planning, design, construction, monitoring, and maintenance. In keeping with Malaysia's objective to reduce carbon emissions by 40% from 2005 to 2020 [8, 9], this strategy concentrates on energy conservation and energy savings in the building industry.

The Energy Conservation Centre Japan (ECCJ), the Danish International Development Agency (DANIDA), the Japan External Trade Organization (JETRO), and the United Nations Development Program (UNDP) have all provided funding for some of these efforts [10, 11].

These initiatives have helped to strengthen the nation's capabilities in several areas related to energy efficiency. Additionally, it has raised awareness of energy efficiency among stakeholders, the private sector, and users of energy in general. The initiatives also opened the path for the execution and development of energy. The use of renewable energy has also been emphasized in policy, not only in Malaysia but also in other East and Southeast Asian nations [12, 13].

Buildings must now comply with energy conservation laws in several countries around the world, according to an earlier study [14, 15]. As a result, in nations like Singapore, Thailand, the Philippines, Indonesia, and Malaysia, the standard energy-efficiency value of the building cannot be higher than a permissible threshold [16, 17]. The basis of OTTV and RTTV is used to examine the heat gain over the building's envelope to maintain compliance. It refers to the typical rate of heat gained through the wall into the conditioned space. The glazing composition and other opaque parts of the envelope, such as the sun-shading mechanisms, are taken into mind in its construction [18]. Additionally, it shows weather-related details like the average temperature for the area and the effects of solar radiation.

A previous study mentioned the best strategy to lower energy use is through the design of energy-efficient buildings [19]. This is because the exterior of the structure acts as a barrier between the inside and exterior environments. The façade of a structure has a significant impact on its thermal efficiency, second only to the local climate. All types of buildings have the potential to save energy, but energy-intensive structures like air-conditioned offices and shopping centers are particularly problematic [20].

In addition to this, Building Information Modeling (BIM) is well-known as a holistic process of creating and managing information about a built asset [21]. BIM is a recognized new technology that can aid in sustainable design, particularly energy efficiency, by enabling architects and engineers to analyze, simulate, and visualize building performance—tasks that were previously done during the design process [22]. BIM is beneficial for scheduling, planning, implementing, and facilities management since it increases flexibility and profitability. When building work is envisioned and carried out using BIM from the viewpoint of stakeholders, owners, designers, contractors, and management teams can collaborate more successfully [23, 24]. BIM technology is consequently attracting a lot of interest from experts. Information and communication technology (ICT) utilization could assist in resolving some of the present problems because of change.

Among the most well-known BIMs is Autodesk Revit, a program for creative technology modeling designed for architects, landscape architects, structural engineers, mechanical, electrical, and plumbing engineers, designers, and contractors. Founded in 1997 as Charles River Software, the company was renamed Revit Technology Corporation in 2000, and Autodesk purchased it in 2002. Charles River Software was the original developer of the software. Autodesk Revit has been extensively utilized to help the reality-based parametric modeling process, either directly through manual family creation [25] or commercial plugins [15], such as Scan-to-BIM and Leica CloudWorx. The components are distributed in a complex 3D space, and manual manufacture is time-consuming due to the plugins' high cost and standard-building status [26].

The Revit API (Application Programming Interface) incorporates the parametric modeling and user features of the BIM [23, 25]. The interface programming methods give designers the ability to interactively design and manipulate Revit components using computational logic and algorithms. Revit can provide the UI interface, acts as the significant forum and database for display, and parametrically represents the person and constructs the relationship automatically. The software will reduce manual operation and carry out automation, and batch processing considers different functions [17]. Also, the current algorithms and libraries can be implemented and performed directly. They can, therefore, simultaneously automate the segmentation of elements and the parametric representation procedure in the BIM setting employing specific functions.

In this research, we present an automated system that promotes effective design building with the aid of a BIM plugin and Revit API. By automating procedures that would ordinarily require manual involvement, Revit API enables BIM modeling organizations to streamline their workflows. For instance, it can offer automated clash detection, which would help the team save significant time and resources. Additionally, it can make the process of making unique sheets and views for drawings simpler, increasing the precision and consistency of output.

Our automated system is mainly to investigate and enhance the digital building design approach by calculating the associated energy efficiency. In the next section 2, the two principal Malaysian energy standard codes, MS2860 and MS1525, which establish sustainable energy standards for residential and non-residential structures, are discussed. Following that, energy-efficient construction is explored in section 3 along with a description and explanation of the OTTV and RTTV formulas. A full explanation of each required parameter value is also presented. Subsequently, information on the OTTV and RTTV plugin implementation process is illustrated along with the associated pseudocodes in section 4. In the final section, the evaluation is observed, discussed, and the final conclusions are drawn.

## 2- Malaysia Code of Energy Consumption Standard

Since 2001, the OTTV code has been taken into account in Malaysian Standard, especially for commercial conditioning structures [26]. The Malaysian Energy Consumption Codes (also known as the Malaysian Standard, MS) were designed primarily to enhance quality, standardization, and accreditation for the benefit of the national economy. Additionally, it supports public health and safety, protects consumers, fosters domestic and international trade, and advances international collaboration [27, 28].

In-depth, the main concern of the Malaysian Standard is to consider heat gain through building windows as a critical element. The OTTV Equation has typically relied on four key parameters: the U-value of structural materials, solar absorption, window-to-wall ratio, and shading coefficient. This is because energy queries on the interior environment's cooling have led to this dependence. The heat uptake through the envelope has been significantly impacted by these factors [26, 29]. All coefficients, including absorptivity value, fenestration factors, and shading coefficient, have an impact on the OTTV value for walls or roofs. These were determined using a variety of simulations and investigations to accurately match Malaysia's climate features with the equation data.

In Malaysia, MS2860 for residential buildings and renewable energy use and MS1525 for non-residential structures and sustainable energy use are the two main energy efficiency construction standards.

The MS1525 in Clause 5.2 states that the Overall Thermal Transfer Value (OTTV), a design parameter that quantifies the solar thermal load transmitted through the building envelope but excludes the thermal of the roof (Roof Thermal Transfer Value, RTTV), must be less than 50 W/m$^2$ [25]. However, the same law specifies that the roof's thermal conductivity (Roof Thermal Transfer Value, RTTV) value must be less than 25 W/m$^2$ [25].

## 3- Analysis of Energy Efficiency Building

The solar thermal charge transmitted through the structure's envelope is indicated by the design parameters OTTV and RTTV. Only a few tactics follow the standard, including the choice of glass, window size, outside wall lighting, wall color, ceiling style, and roof form in the early design stage. Limiting the window-to-wall ratio, constructing shade devices with heat-control glass, and using materials with a high insulation value are further methods for lowering the OTTV [24]. Additionally, these methods seek to reduce energy transmission, which previously occurred mostly through roofs and walls. High resistance (R-value) windows and walls can also reduce the rate of heat transmission. The window opening size needs to be optimized to reduce heat transfer from the window into the building [18].

Solar heat gain through the building envelope is one of the major elements of the refrigeration charge for an air-conditioned structure. Thermal discomfort is brought on by solar heat buildup in structures without air conditioning. The benefit of a building is therefore an important factor in the design of energy efficiency to reduce solar radiation. The design parameter equivalent to the solar thermal charge transmitted through the structure's envelope is indicated by the abbreviations OTTV and RTTV. Numerous strategies, such as the selection of glass, window size, outside wall lighting, wall color, ceiling style, and roof form at the preliminary design stage, meet the requirement.

Limiting the window-to-wall ratio, creating shade devices utilizing heat-control glass, and employing materials with a high insulating value are further strategies for lowering the OTTV and reducing energy transfer, which was primarily carried through walls and roofs [24]. Heat transfer can be slowed down by using windows and walls with high resistance (R-values). To minimize heat transfer into the building through windows, the window opening size must be optimized [18].

### 3-1- Overall Thermal Transfer Value (OTTV)

OTTV is a value that shows the average rate of heat transfer through the building envelope into a building. The term building envelope refers to a building's outermost layer. It includes all sides' roofs, walls, and windows.

The definition of overall thermal transfer value (OTTV) was first developed in the United States by ASHRAE Standard 90A-1980 to gauge the average heat gain through a building envelope. The definition of OTTV in Malaysia is introduced in Malaysian Standards 1525 [8, 17] the regulation governs the OTTV of less than 50 W/m$^2$ for air-conditioned areas of more than 4000 m$^2$.

The OTTV technically measures heat transfer by conducting through an opaque surface through a building envelope, conduction through a glass window, and solar radiation through a glass window. Measuring OTTV is based on four critical parameters, namely Window-to-Wall Ratio (WWR), Shading Coefficient (SC), U-values, and solar absorption (α). With a more significant effect on U-value and solar absorption than other residential OTTV parameters [18].

There are several types of formulation to calculate, which proposed the OTTV by researchers [2, 21, 22]. One of them is a formulation based on MS1525 [17], as shown in Equation 1:

$$OTTV = \frac{(A_1.OTTV_1)+(A_2.OTTV_2)+ \ldots + (A_n.OTTV_n)}{A_1+A_2+ \ldots + A_n} \tag{1}$$

where, $A_1$ is the gross exterior wall area for orientation 1, and $OTTV_1$ is the overall thermal transfer value for direction 1 parameter A can be extracted from the model from each wall element.

The $OTTV_1$ is defined as shown in Equation 2.

$$OTTV_1 = 15. \propto. (1 - WWR).U_w + \left(6.WWR.U_f\right) + (194.OF.WWR.SC) \tag{2}$$

where the parameters are shown in Table 1.

**Table 1. The basic definition of OTTV formulas**

| Notation | Description |
|---|---|
| $\propto$ | is the opaque wall solar absorptive |
| WWR | is the exterior wall to windows the gross ratio |
| $U_w$ | is opaque wall thermal transmittance (W/m$^2$K) |
| $U_f$ | is the fenestration device thermal transmittance (window element) (W/m$^2$K) |
| OF | is the factor of solar orientation |
| SC | is the system fenestration coefficient for shading |

The $\propto$ value can be obtained based on the catalog of paint color from the factory or can be used as the one of standard, shown below, in Table 2 [5].

**Table 2. The standard value for solar absorptivity ($\propto$)**

| Paint Colour | Solar Absorptivity ($\propto$) |
|---|---|
| Light | < 0.40 |
| Medium | to 0.70 |
| Dark | > 0.70 |

Parameter $U_w$ is the thermal transmittance of the opaque wall value (known as Heat Transfer Coefficient ($U$) at wall element in the Revit Model parameter) that can be extracted from the model based on which wall material is used. The next parameter, $U_f$ is the thermal transmittance of the fenestration system value (also known as Heat Transfer Coefficient ($U$) at window element in the Revit Model parameter) and can be extracted as well.

For solar orientation factor (OF) value can be obtained based on Table 3 [5].

**Table 3. Solar Orientation Factor**

| Orientation | Solar Heat Gain Coefficient (OF) |
|---|---|
| North | 0.90 |
| Northeast | 1.09 |
| East | 1.23 |
| Southeast | 1.13 |
| South | 0.92 |
| Southwest | 0.90 |
| West | 0.94 |
| Northwest | 0.90 |

Equations 3 and 4 show the formula related to OTTV.

$$WWR = \frac{\sum windows\ area\ (m^2)}{\sum gross\ exterior\ wall\ area\ (m^2)} \tag{3}$$

$$SC = SC_1.SC_2 \tag{4}$$

where, $WWR$ is the wall-window ratio and the $SC_1$ is the shading coefficient of sub-system 1 (one), the fenestration system, e.g., glass (also known as the Solar Heat Gain Coefficient), which can be extracted from the Revit model, and $SC_2$, the shading coefficient of sub-system 2 (two), e.g., external shading devices [17].

To calculate the $SC_2$, the formula of calculation based on the type of external shading was extracted from the Revit model. There are three possible types of external shading; the first type is horizontal external shading devices, as shown in Figure 1, then in Equation 5, as the formula of calculation is used.

$$R_1 = \frac{x}{y} \tag{5}$$

where x is overhanging distance, and y is the distance from overhang to the windowsill. Using $R_1$, the $SC_2$ value can be obtained from the horizontal projection shading coefficients, as shown in Table 4
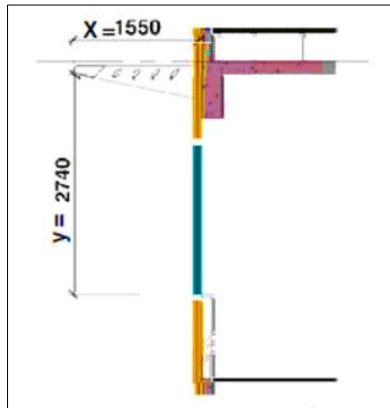


**Figure 1. Horizontal external shading device**

**Table 4. Horizontal projection shading coefficients**

| $R_1$ | 0.3 to 0.4 | 0.5 to 0.7 | 0.8 to 1.2 | 1.3 to 2.0 |
|---|---|---|---|---|
| North/South | 0.77 | 0.71 | 0.67 | 0.65 |
| East | 0.77 | 0.68 | 0.60 | 0.55 |
| West | 0.79 | 0.71 | 0.65 | 0.61 |
| NE/SW | 0.77 | 0.69 | 0.63 | 0.60 |
| NW/SE | 0.79 | 0.72 | 0.66 | 0.63 |

The second type is vertical external shading devices, as shown in Figure 2, the formula shown in Equation 6, is used.

$$R_2 = \frac{vp}{l} \tag{6}$$

where $vp$ is the width of the vertical projection, and $l$ is the length of the fenestration. Using the $R_2$ result, the $SC_2$ value can be obtained from the horizontal projection shading coefficients, as shown in Table 5 [17].



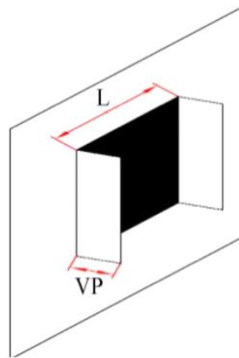**Figure 2. Vertical external shading device**

**Table 5. Vertical projection shading coefficients**

| $R_2$ | 0.3 to 0.4 | 0.5 to 0.7 | 0.8 to 1.2 | 1.3 to 2.0 |
|---|---|---|---|---|
| North/South | 0.82 | 0.77 | 0.73 | 0.70 |
| East | 0.87 | 0.82 | 0.78 | 0.75 |
| West | 0.86 | 0.81 | 0.77 | 0.74 |
| NE/SW | 0.83 | 0.77 | 0.72 | 0.69 |
| NW/SE | 0.84 | 0.79 | 0.74 | 0.71 |

The last possibility is both of type external shading devices exist in the model, and Figure 3 can be used to obtain the $SC_2$ value.

**EGG CRATE SHADING COFFICIENTS**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | 0.20 | 0.20 | 0.20 | 0.40 | 0.40 | 0.40 | 0.60 | 0.60 | 0.80 | 0.80 | 1.00 | 1.00 | 1.00 | 1.2 to 1.8 |
| R2 | 0.20 | 0.4 to 0.6 | 0.6 to 0.8 | 0.2 to 0.4 | 0.6 to 1.2 | 1.4 to 1.8 | 0.2 to 0.6 | 0.8 to 1.8 | 0.2 to 0.6 | 0.8 to 1.8 | 0.2 to 0.4 | 0.6 to 1.2 | 1.4 to 1.8 | 0.2 to 1.8 |
| North/South | 0.71 | 0.62 | 0.56 | 0.59 | 0.49 | 0.46 | 0.52 | 0.43 | 0.5 | 0.4 | 0.51 | 0.41 | 0.38 | 0.38 |
| East | 0.77 | 0.69 | 0.62 | 0.63 | 0.54 | 0.5 | 0.54 | 0.44 | 0.49 | 0.39 | 0.48 | 0.39 | 0.35 | 0.33 |
| West | 0.77 | 0.69 | 0.61 | 0.64 | 0.54 | 0.51 | 0.56 | 0.46 | 0.52 | 0.42 | 0.52 | 0.42 | 0.38 | 0.38 |
| NE/SW | 0.73 | 0.63 | 0.55 | 0.6 | 0.48 | 0.44 | 0.51 | 0.39 | 0.47 | 0.36 | 0.48 | 0.36 | 0.32 | 0.32 |
| NW/SE | 0.75 | 0.66 | 0.58 | 0.63 | 0.52 | 0.48 | 0.55 | 0.44 | 0.52 | 0.41 | 0.52 | 0.42 | 0.38 | 0.38 |

**Figure 3. Horizontal and vertical projection shading coefficients**

From Equation 1, it can be determined that solar radiation is the more significant contributor to the OTTV through a glass window. Usually, depending on the glass area, it contributes about 70 – 80% of the total OTTV value. To ensure the OTTV value does not exceed 50 W/m$^2$, changing the type of glass window will allow a contribution of approximately 30 – 80%, reducing the OTTV value.

The part of the formulation that gives the OTTV value a primary contribution is heat conduction through the window. It could contribute about 10 - 20% to the OTTV value. The last element is heating conduction through opaque walls, which only adds 0.5 to 5% to the cost of OTTV.

### 3-2- Roof Thermal Transfer Value (RTTV)

The RTTV is often measured using similar formulas, with the window-to-wall ratio translating into a skylight ratio to the roof, and the heat transfer coefficient corresponding to the building's composition. The formulation for the wall, without and with skylight, as seen in Equations 7 and 8, respectively [17]:

$$\frac{A_r.U_r.TD_{eq}}{A_r} \tag{7}$$

$$\frac{(A_r.U_r.TD_{eq}) + (A_s.U_s.\Delta T)+(A_s.SC.SF)}{A_0} \tag{8}$$

where the parameters are shown in Table 6.

**Table 6. Vertical projection shading coefficients**

| Notation | Description |
|---|---|
| $A_r$ | is the opaque roof layer (m$^2$) |
| $U_r$ | is the opaque roof layer thermal transmittance (W/m$^2$k) |
| $TD_{eq}$ | is the equivalent temperature difference (k) |
| $A_s$ | is the roof skylight layer (m$^2$) |
| $U_s$ | is the thermal transmittance of the skylight layer (W/m$^2$) |
| $\Delta T$ | is the temperature difference between exterior and interior architecture (5K) |
| SC | is the skylight shading coefficient |
| SF | is the solar factor (W/m$^2$) |
| $A_0$ | is the gross roof layer (m$^2$): $A_0 = A_r + A_s$ |

Parameter $A_r$, the opaque roof area value of the roof element can be extracted from the model. Another parameter, $U_r$. The thermal transmittance of the roof area value can be calculated from Equations 9 and 10, as shown below:

$$U = \frac{1}{R} \tag{9}$$

$$R = \frac{t}{k} \tag{10}$$

where, $t$ is the roof thickness, and k is the roof thermal conductivity based on the roof material, which can be extracted from the model. To obtain the roof material thermal conductivity value (k), we must be ensured, the Thermal Tab in the material browser of the Revit model is available and already set with a specific material that used.

Next parameter, $TD_{eq}$, can be obtained based on this rule, as shown in Equation 11:

$$TD_{eq} = \begin{cases} w < 50 \, kg/m^2 & 20 \\ other & 24 \end{cases} \tag{11}$$

Based on Equation 11, we need to calculate the\ w parameter, which is the roof's weight, using Equation 12, as shown below.

$$w = t \times d \tag{12}$$

where, $t$ is the roof thickness, and d is roof material density. The d parameter can be obtained from the model.

## 4- Implementation of Energy Efficiency Building based on the Revit API plugins

The plugins of the Revit API were generated based on their basic prototype, and the simulation-related parameters were then extracted from the BIM model. The Revit API plugin development is used in this study, based on C# programming. Microsoft's tool Visual Studio 2019 was selected as an Integrated Development Environment (IDE).

### 4-1- Overall Thermal Transfer Value

The OTTV measurement was carried out based on three processed stages. Firstly, it calculates the model's initialization document the Revit model. The filtering object was created in the second step to pick the elements in the walls and windows. In the final stage, the information of the walls and windows features are extracted from the base model, and the OTTV formula is determined. Figures 4 and 5 display the OTTV plugin snipped C # coding in the Revit, and the algorithm pseudocode to clarify the processing information for obtaining and measuring the OTTV, respectively.

```csharp
        }
    string resultPath = textBox1.Text;
    Directory.CreateDirectory(resultPath);
    string docName = _doc.Title;
    string docPath = _doc.PathName;
    string fileName = Path.Combine(resultPath, "OTTV_" + docName + Tools.GetSpanTime() + ".csv");

    using (StreamWriter file = new StreamWriter(fileName))
    {
        FilteredElementCollector collector = new FilteredElementCollector(_doc);
        List<BuiltInCategory> listOfCategory = new List<BuiltInCategory>();
        listOfCategory.Add(BuiltInCategory.OST_Walls);
        listOfCategory.Add(BuiltInCategory.OST_Windows);

        ElementMulticategoryFilter filter = new ElementMulticategoryFilter(listOfCategory);
        IList<Element> listOfElement = collector.WherePasses(filter).WhereElementIsNotElementType().ToElements()
            .OrderBy(x => x.Category.Name).ToList();

        foreach (Element elItem in listOfElement)
        {
            // get category name
            string categoryName = elItem.Category.Name;

            string Hostid = " - ";

            // get Element Type
            Element elType = _doc.GetElement(elItem.GetTypeId());
            if ((categoryName == "Walls" && Tools.IsExterior(elType)) || categoryName != "Walls")
```

**Figure 4. C# Code of OTTV plugin**

```
1:    initialize active document form Revit
2:    create a filter for wall and window elements
3:    get these elements and order by category
4:    for each element :
5:        get category's name
6:        if (wall and isExterior) or windows :
7:            get id of element
8:            get name of element
9:            get area of element
10:           get heat transfer coefficient (U_w and U_f)
11:           if wall :
12:               get facing direction of wall
13:           endif
14:           if window :
15:               get host id of window
16:               get wall element by host id of the window
17:               get the wall direction
18:               get solar heat gain coefficient (OF)
19:               get shading coefficient (SC) based on shading element
20:           endif
21:       endif
22:   endfor
23:   foreach direction of the wall :
24:       get solar absorption value based on their direction
25:       select all elements which have the same direction
26:       foreach element :
27:           calcaluate the total area of all walls
28:           calculate the total area of all windows
29:           calculate window to gross exterior wall ratio (WWR)
30:       endfor
31:       calculate heat conduction through walls (15 . α . (1 − WWR) . U_w)
32:       calculate heat conduction through windows (6 . WWR . U_f)
33:       calculate solar heat gain through windows (194 . OF . WWR . SC)
34:       calculate OTTV for this direction
35:   endfor
36:   calculate the total of OTTV
```

**Figure 5. Pseudocode of OTTV calculation**

Figure 5's pseudocode illustrates the process of initializing the document model at line 1 (phase 1), generating the filter at line 2 into 22 shows, and extracting information from each element, including the wall's direction (phase 2). Each OTTV's orientation was determined at lines 23 through 35 based on how it was oriented. As a result, step three of the pseudocode included an estimation of the OTTV final value.

Next, Figure 6 depicts the building model that we utilized in this experiment, derived from the Revit application, and Figure 7 displays the OTTV results for each direction and the overall OTTV value. According to the results, the OTTV model only receives 42.72 W/m$^2$, which is less than the average value for Malaysia (50 W/m$^2$) [17].



**Figure 6. Building model from Revit Application used in this experiment**

| Elevation | Area (m$^2$) | WWR | Solar_Absorptivity | Heat Conduction (W/m$^2$) | | Solar Orientation Factor | Shading Coefecient | OTTV |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | Opaque Walls | Glass Windows | | | |
| North | 463.55 | 19% | 0.32 | 1 | 1 | 0.9 | 0.77 | 31.18 |
| East | 390.9 | 30% | 0.32 | 1 | 1 | 1.23 | 0.77 | 61.03 |
| South | 465.12 | 28% | 0.32 | 1 | 1 | 0.92 | 0.77 | 44.09 |
| West | 386.73 | 22% | 0.32 | 1 | 1 | 0.94 | 0.79 | 36.39 |

| OTTV (W/m$^2$) |
| --- |
| **42.72** |

**Figure 7. The OTTV Result**

The % for the wall-window ratio and the OTTV value for each direction are shown in Figures 8 and 9. The east and south direction wall-window rates are 30% and 28%, respectively, as shown in Figure 8. However, Figure 9 demonstrates that the single east orientation has the biggest contribution, at 61.03, in comparison to the other directions, which are, respectively, 44.09, 36.39, and 31.18 in the south, west, and north.
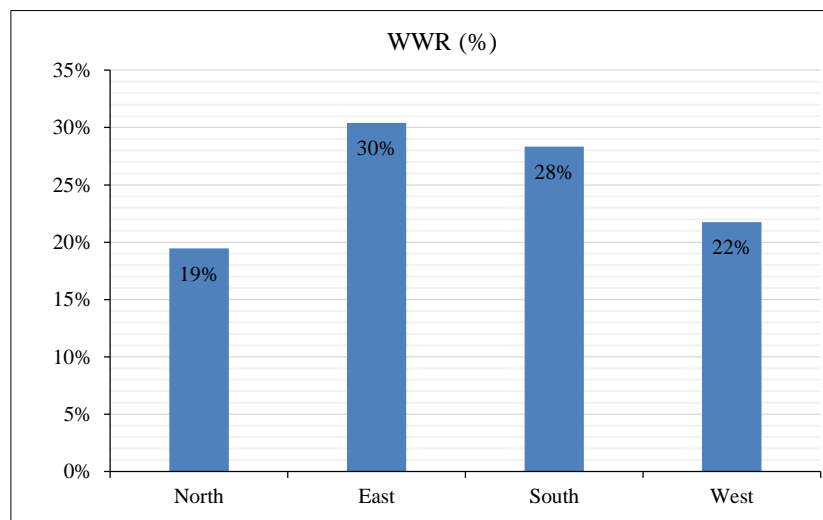


**Figure 8. The wall-window ration (WWR) percentage comparison for each direction**
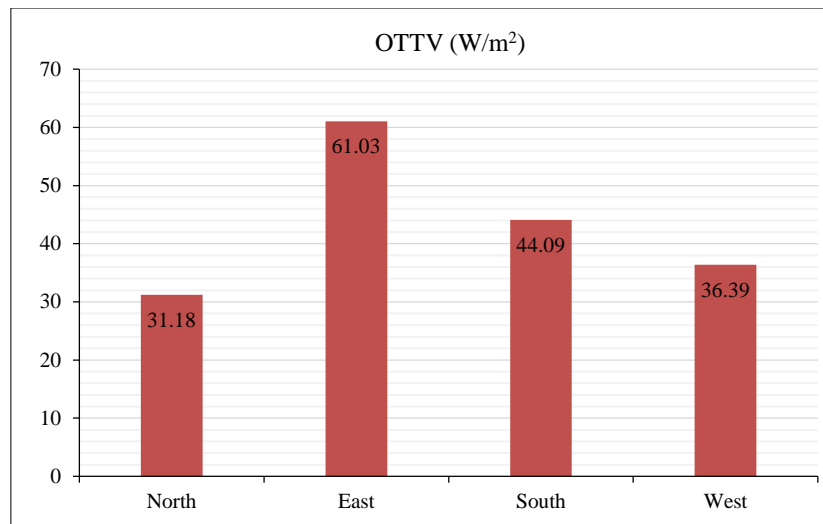
**Figure 9. Comparison of OTTV value for each direction**

Returning to Table 3, we can see that the solar orientation factor (OF) for the east direction is larger than that of the other directions, coming in at1.23.

### 4-2- Roof Thermal Transfer Value

The RTTV formula was determined using the algorithms' pseudocode, as shown in Figure 10.

```
1:   initialize active document form Revit
2:   create a filter for roof elements
3:   for each roof element :
4:       get area of
5:       get thickness (t)
6:       get thermal conductivity based on the material (k)
7:       get density based on material's structure
8:       get the type of roof, with or without a skylight
9:       calculate the R = t/k
10:      calculate the weight of the roof, w = density/area
11:      If w < 50:
12:          TDeq = 24
13:      else
14:          TDeq = 20
15:      endif
16:  endfor
17:  calculate the RTTV value
```

**Figure 10. Pseudocode of RTTV calculation**

RTTV is more straightforward than the measurement on OTTV, it is a straightforward processing calculation. The initialization document model comes first. The filtering object was then created to only select roof-related elements. For each roof, the output data from a few filtering elements was retrieved, including the roof's area, thickness, thermal conductivity, density, and type (skylight or not). Based on that data, the RTTV value had been established. Figure 11 illustrates the RTTV result, which is 8.02 W/m$^2$, which is less than the Malaysian Standard [17].

| # | Roof Area (m$^2$) | Roof Thickness (m) | Roof Material Thermal Conductivity (W/mK) | Thermal Transmittance of opaque roof area - (1/R) (U-value) (W/m$^2$K) | R = thickness / Conductivity | Density (kg/m$^3$) | Weight (kg/m$^2$) = Density * Thickness | Temperature Different (K) | Area * U * TDeg |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1900.8 | 0.18 | 0.06 | 0.33 | 3.00 | 290 | 52.2 | 24 | 15206.4 |
| 2 | 312.63 | 0.18 | 0.06 | 0.33 | 3.00 | 290 | 52.2 | 24 | 2501.04 |
| 3 | 5.51 | 0.08 | 0.06 | 0.75 | 1.33 | 290 | 23.2 | 20 | 82.65 |
| **Total** | **2218.94** | | | | | | | | **17790.09** |
| **RTTV (W/m$^2$)** | | | | | | | | | |
| **8.02** | | | | | | | | | |

**Figure 11. The RTTV result**

# 5- Evaluation of Energy Efficiency Building

The elements and parameters for the total computation, including OTTV, are listed in the plugin that was created for this study. Figure 12 displays the outcomes of an OTTV calculation using the data that was retrieved from the plugin that was created and saved in an Excel format. The created plugin aims to give building designers the greatest user experience possible. A complete list of parameters for elements, such as walls and windows, is shown in the following figure 12, which explains how to calculate OTTP. As a result, it is possible to arrange the element data by direction and produce the calculation parameters indicated in Equation 1. Figure 12 has been set apart into five segments for explanation.



**Figure 12. The result – The list of parameters of element**

Segment 1 contains the details of the element list, such as the wall and windows, while Segment 2 groups the elements by orientation. The computation of A*OTTV is shown in Section 3 using equation 1, where A is the gross exterior wall area for orientation. The OTTV calculation's final value is shown in Section 4, and the standard referenced in Section 5 is MS1524:2007. With the help of this type of plugin, assessment and analysis are simple to perform, especially when considering the list of element parameters.

Based on the model that was employed in this experiment, we provide Figure 13 that also compares the percentages of contributions made by the three components of the OTTV formulation—wall heat conduction, window heat conduction, and window solar heat gain. In contrast to the elevations of 44.09, 36.39, and 31.18 for the south, west, and north, Figure 13 shows that the east elevation is 61.03 for the maximum OTTV contribution. The east direction is highlighted in blue in Figure 14 to show the portion of the wall that contributes the most to OTTV.

| Elevation | Heat Conduction of | | | | Solar Heat Gain of | | OTTV |
|---|---|---|---|---|---|---|---|
| | Walls | | Windows | | Windows | | |
| North | 3.87 | *12%* | 1.17 | *4%* | 26.15 | *84%* | 31.18 |
| East | 3.34 | *5%* | 1.82 | *3%* | 55.86 | *92%* | 61.03 |
| South | 3.44 | *8%* | 1.70 | *4%* | 38.95 | *88%* | 44.09 |
| West | 3.76 | *10%* | 1.30 | *4%* | 31.33 | *86%* | 36.39 |

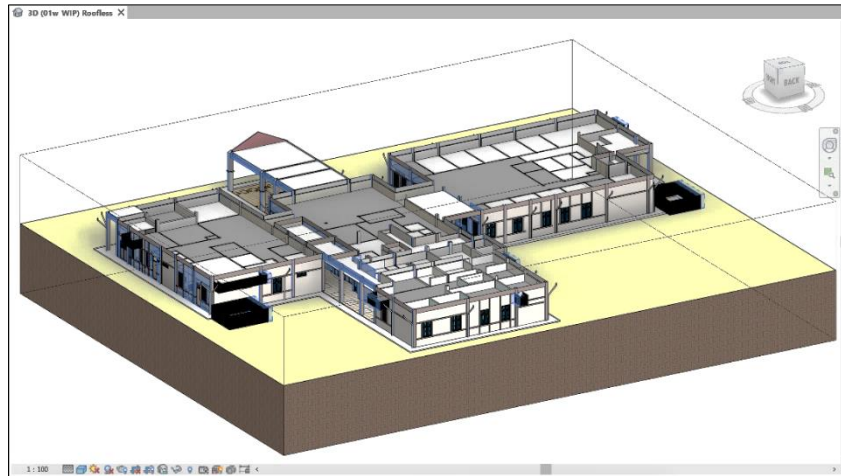**Figure 13. The result – The list of element's parameters**

**Figure 14.** The east area of the wall that contributes the most to OTTV is highlighted in blue

The effect of increasing the window size on OTTV was tested in a different experiment. We gradually decrease the height of windows from 10 mm to 500 mm and then raise them to a higher height using the same number. We ran the same experiment with identical settings to alter the window's width. The results are shown in Figures 15 and 16. When the window's height is increased rather than its width, the difference in OTTV is dispersed over a larger range of lengths.
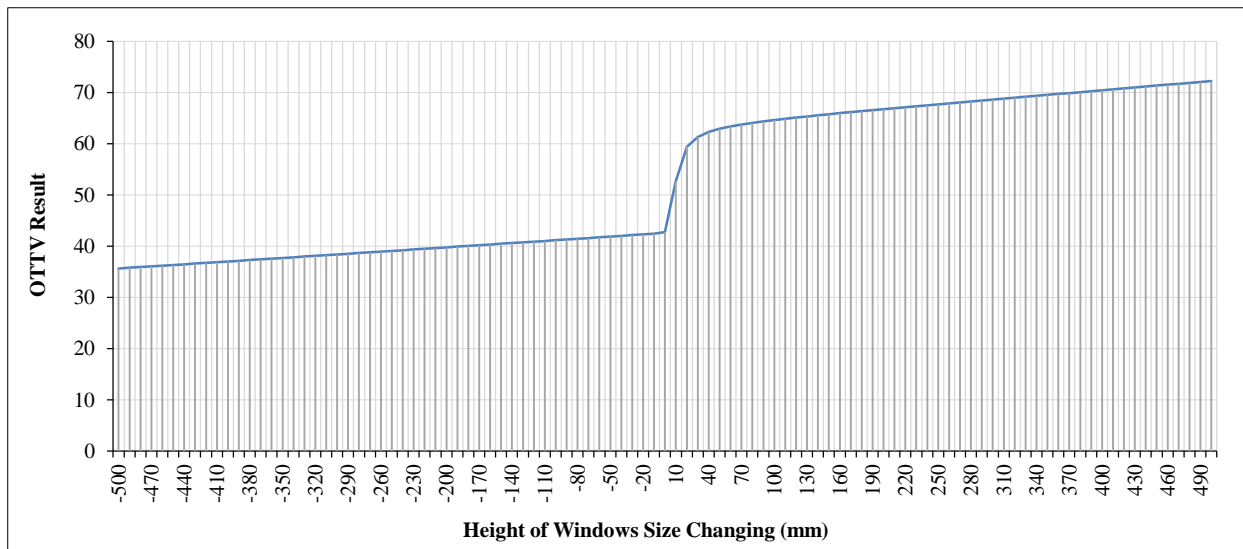


**Figure 15.** The effect of changing window's heights
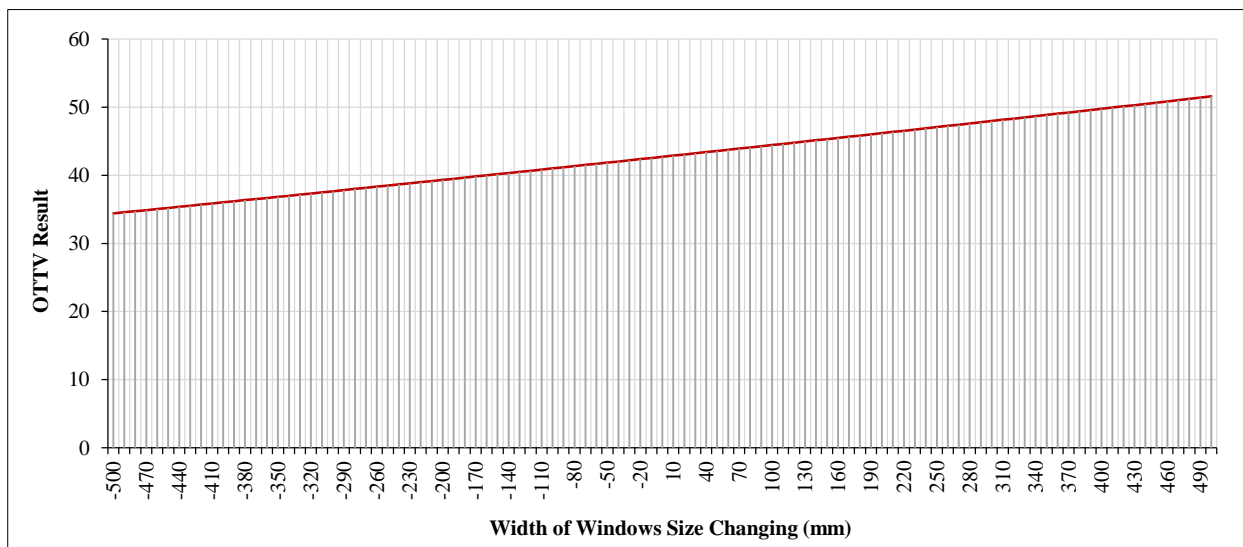


**Figure 16.** The effects of changing window's width

With respect to OTTV value ranges, changing the window's height yields values between 35.64 and 72.24, whereas increasing the window's width only yields values between 34.40 and 51.57. We can infer from these findings that the height size of the window affects the OTTV value more than the width size, but more analysis and experiments are required to confirm this.

## 6- Conclusion

The automatic energy analysis, which involves measuring and modeling energy-efficient buildings, has been made possible by the plugin that was constructed using the Revit API and linked to our suggested program. Since the building designers may modify the material of the element-related walls, windows, roofs, and other characteristics as necessary, it is vital for them to quickly optimize energy usage for the building as early as possible from the design stage. Using our application, one can obtain the measurement result instantly and interactively. To maximize the accuracy of OTTV and RTTV computations and to offer a variety of simulations, it is critical to obtain the correct value for each element's utilization, such as walls, windows, and roofs, including their material parameter value. This has been provided by our application. The objective of our forthcoming research is to enhance the models we have developed in this work so far. For example, we might change the material of the walls and windows and alter the size of the windows to get the tiny value of OTTV, RTTV, or another standard measurement on energy efficiency. This makes the study a multi-objective issue that can be resolved using a variety of optimization techniques, including the Firefly Algorithm and Particle Swarm Optimization (PSO).

## 7- Declarations

### 7-1- Author Contributions

Conceptualization, T.B.K. and F.U.; methodology, D.A.D.; software, T.B.K.; validation, F.U., F.F., and D.A.D.; formal analysis, T.B.K. and D.A.D.; investigation, F.F.; resources, D.A.D.; data curation, F.U.; writing—original draft preparation, T.B.K. and F.U.; writing—review and editing, D.A.D.; visualization, T.B.K.; supervision, D.A.D.; project administration, D.A.D.; funding acquisition, D.A.D. All authors have read and agreed to the published version of the manuscript.

### 7-2- Data Availability Statement

The data presented in this study are available in the article.

### 7-3- Funding

### 7-4- Institutional Review Board Statement

Not applicable.

### 7-5- Informed Consent Statement

Not applicable.

### 7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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